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Flatfish Stock Assessments for the west coast of Canada for 1999 and Recommended Yield Options for 2000

Jeff Fargo

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C. V9R 5K6

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-Abstract-

Interim assessments were prepared for important stocks of flatfish caught in the B.C. trawl fishery. A summary of landing statistics including the observations from the 1997 fishery is presented for all of these. New data was available for only two stocks, Hecate Strait rock sole and Hecate Strait English sole. The catch-age analyses for those two stocks have been updated. There is no change in any of the yield recommendations from last year.

Landings for Area 3C-D and 5C-E Dover sole increased in 1998. Landings for the 3C-D stock were near the low end of the recommended yield range identified last year while 1998 landings for the 5C-E stock were near the upper limit of the recommended yield range identified last year.

Rock sole biomass in Areas 5C-D in 1998 declined slightly from 1997 but remains above the long-term average for the last 50 years. The estimate of fishing mortality for the stock in 1998, was F =0.13, below $F_{0.1}$ (F=0.22). With fixed exploitation at this level there is a 0.91 probability that the stock will maintain its spawning biomass and ensure the recruitment necessary to sustain itself in the future.

English sole biomass in Areas 5C-D in 1998 declined from 1997 to a level near the long-term average for the last 50 years. The estimate of fishing mortality for the stock in 1998 was F=0.16, below $F_{0.1}$ (F=0.25). With fixed exploitation at this level there is a 0.88 probability that the stock will maintain its spawning biomass and ensure the recruitment necessary to sustain itself in the future.

-Résumé-

Des évaluations provisoires ont été effectuées pour d'importants stocks de poissons plats faisant l'objet de la pêche au chalut en C.-B. Un sommaire des statistiques sur les débarquements, y compris les observations touchant la pêche de 1997, est présenté pour tous ces stocks. De nouvelles données n'ont été obtenues que pour deux stocks, celui de la fausse limande du détroit d'Hecate et celui du carlottin anglais du détroit d'Hecate. L'analyse des captures selon l'âge a été mise à jour pour ces deux stocks. Aucune modification n'est proposée pour les recommandations de rendement, par rapport à l'an dernier.

Les débarquements de limande-sole en provenance des zones 3C-D et 5C-E ont augmenté en 1998. Les débarquements du stock de 3C-D approchaient la limite inférieure de la gamme de rendement définie l'an dernier tandis que ceux de 1998 du stock 5C-E étaient près de la limite supérieure recommandée identifiée l'an dernier.

La biomasse de fausse limande des zones 5C-D en 1998 a diminué légèrement par rapport à 1997 mais demeure supérieure à la moyenne à long terme des 50 dernières années. La mortalité par pêche estimée du stock en 1998 (F=0,13) était inférieure au niveau $F_{0.1}$ (F=0,22). Un taux d'exploitation fixe à ce niveau correspond à une probabilité de 0,91 que le stock

conserve sa biomasse de géniteurs et garantit le recrutement nécessaire au maintien du stock dans le futur.

La biomasse du carlottin anglais dans les zones 5C-D en 1998 a diminué par rapport à 1997 et atteint un niveau approchant la moyenne à long terme des 50 dernières années. La mortalité par pêche estimée du stock en 1998 (F=0,16) en deçà de la valeur $F_{0.1}$ (F=0,25). Un taux d'exploitation fixe à ce niveau correspond à une probabilité de 0,88 que le stock conserve sa biomasse de géniteurs et garantit le recrutement nécessaire au maintien du stock dans le futur.

1.0.1. General Introduction

This year interim assessments have been prepared for Hecate Strait Rock sole (*Lepidopsetta bilineata*) and English sole(*Parophrys vetulus*) and Area 3CD and 5CDE Dover sole (*Microstomus pacificus*). Landing statistics have been updated to include information from the 1998 fishery. Landings, 25 % qualified effort and median CPUE are presented for Area 3C-D Dover sole and Area 5C-E Dover sole and Hecate Strait Rock sole and English sole. In addition, the catch-age analysis has been updated for the assessments of Hecate Strait Rock sole and Hecate Strait English sole.

The groundfish trawl fishery has changed significantly in recent years. Changes in the management of groundfish fisheries including observer coverage, vessel quotas and changes in vessel catching coefficients over time have nullified the comparison of fishery CPUE over time. As well, the hyperstability of this index has been documented for many situations. Fishery CPUE often does not provide a signal of stock decline until the stock has been depleted (Hillborn and Walters 1992, Richards and Schnute 1986). Accordingly, CPUE is not used as the basis of assessment for any of the cases presented here. The median statistic has been presented for each case as a gross indicator of abundance for select periods of time where there was no regulatory effect and differences in fleet catching coefficients were negligible. In the presence of skewed observations, both the mean of ratios and the ratio of means of CPUE perform badly as they are sensitive to a small number of outliers. The median or 50% trimmed mean provides a robust alternative to the two former statistics (Fargo and Kronlund 1997).

For Hecate Strait Rock sole and English sole the state space model of Schnute and Richards (1995) was applied to a time series of age composition data to estimate stock biomass and recruitment. Yield for these cases was determined using the 25^{th} and 50^{th} percentiles of the 95% confidence region for the 1998 biomass estimate using the fishing mortality reference point $F_{0.1}$. Yield options for 1999 and 2000 are summarised in Table 1.1.

1.1. Coastwide

Yield options are not proposed for flatfish species on a coastwide basis.

1.2. Strait of Georgia

Yield options are not proposed for flatfish for this region.

1.3. West Coast of Vancouver Island (Areas 3C and 3D)

1.3.1 Area 3CD Dover sole

1.3.1.1 Area 3CD Introduction

Significant commercial quantities of Dover sole *(Microstomus pacificus)* occur along the Pacific coast from California to Alaska. Dover sole abundance has been shown to decrease with increasing latitude (Westrheim *et al.* 1992). Results of U.S. tagging studies indicate that a number of individual stocks exist along the Pacific coast and that there is minimal intermingling of the adults among stocks (Westrheim *et al.* 1992). However, the larvae of this species undergo a prolonged pelagic phase offshore that can last as long as two years. Thus, the larvae of different stocks probably intermingle extensively. The population off the West Coast of Vancouver Island is probably a discrete stock. Dover sole become vulnerable to the commercial trawl fishery at about 5 years of age but are not fully recruited until age 7-8 (Fargo and Workman 1995). Adults undertake a bathymetric migration from shallow (140-200 m) to deep (400-800 m) water for spawning (Westrheim *et al.* 1992). They spawn over a six month season (December-May) and spawning is age specific with older fish spawning earlier than younger fish (Hunter *et al.* 1992). The maximum age for Area 3CD Dover sole estimated from biological samples collected to date is 49 years (Fargo and Workman 1995).

1.3.1.2 Area 3CD Management History

The Area 3CD Dover sole fishery was unregulated prior to 1992. In 1992, a 20,000 lb (9 t) trip limit was invoked after 70% of the quota was caught. Since 1992, variable trip limits less than 50,000 lbs (23 tons) have been used to manage the fishery. During the period from 1988 to 1996, trips where less than 50,000 lb (23 t) of Dover sole were landed accounted for 60%-95% of the total landings from this area. Trips greater than 50,000 lb (23 t) were not permitted after 1993 and in 1996 the trawl fleet went to IVQs. Landing statistics from the commercial fishery have been updated for this assessment using data from the 1997 fishery.

1.3.1.3 Area 3CD Commercial Catch and Effort Data

Landing statistics for Area 3CD Dover sole are presented in Table 1.2. CPUE and effort statistics for 1996 through 1998 are not directly comparable to those for previous years because the estimates are determined from observations made by at-sea observers while estimates for previous years were determined from logbook information recorded by the vessel captains (Fargo and Kronlund 1997). Landings of Area 3CD Dover sole in 1998 were 1092 t compared to

788 t in 1997. Effort was similar for 1997 and 1998, 1876 h and 1829 h, respectively. Median CPUE increased to 0.349 t/h in 1998 from 0.263 t/h in 1997.

1.3.1.4. Stock status

Evidence from a biomass survey conducted in 1995 (Fargo and Workman 1995) suggests that this stock is fully exploited. There were no biological samples collected from the 1997 and 1998 fisheries so no new analysis has been done. Landings in 1998 were near the low end of the yield range recommended last year. As well, fishing effort in 1998 remained near the level observed in 1997.

1.3.1.5.1 Recommendations and yield options

There is no change in the yield recommendations from last year for this stock.

Low-risk yield option:

A yield of 1000 t is sustainable based on analysis of data collected during a biomass survey of this area conducted in 1995.

High-risk yield option:

Yields above 1500 t observed from 1991 to 1995 are associated with a significant decline in the commercial CPUE index. A yield of 1500 t can be considered as an upper limit of the sustainable range for this stock.

1.5. HECATE STRAIT (Areas 5C and 5D)

1.5.1. Rock sole - Hecate Strait

1.5.1.1. Introduction

Stock delineation work of Ketchen (1982) and Fargo and Westrheim (1987) indicates that there are probably several stocks of Rock sole in Hecate Strait. However, these stocks are treated as a unit for assessment and management. An age composition data series is available for Rock sole caught in the fishery taking place at Two Peaks and Butterworth fishing grounds at the north end of the Strait. Past work has suggested that both density-dependent and density-independent factors regulate the abundance of this species. Spawning biomass and ocean temperature at the time of spawning are two significant determinants of recruitment. Low recruitment has been associated with low spawning biomass and warm ocean temperatures during larval development (Forrester and Thomson 1969, Fargo and McKinnell 1989).

Recruitment for these stocks has fluctuated over time with the last significant increase occurring during the late 1980s and early 1990s. For this assessment a fishery update is provided which includes landing statistics from the 1998 fishery. The age composition data series has been updated with samples from the 1998 fishery and that analysis forms the basis for this assessment.

1.5.1.2. Landing statistics

Landing statistics for Rock sole in Hecate Strait are presented in Table 1.3. Annual statistics for the 1945-98 period are calculated directly from data observations. No detailed data records exist prior to 1954 and the index of Forrester and Thomson (1969) has been used.

Landings in 1998 declined to 576 t from 677 t in 1997while effort in 1998 declined to 2395 h from 2667 h in 1997. Median CPUE decreased slightly to 0.182 t/h in 1998 from 0.191 t/h in 1997. Since the early 1980s there has been little contrast in the commercial CPUE series. Area-specific trip limits have influenced the fishing patterns of the fleet in the past. In 1996, individual vessel quotas were applied along with at-sea observers on all option A vessels. This has resulted in more comprehensive fishery data but prevents direct comparison of these data with data collected in previous years.

1.5.1.3 Catch-age Analysis

The Rock sole age composition time series was updated with biological data collected during the 1998 trawl fishery. Only samples collected from Minor Area 4 (Major Area 8) between 1945 and 1998 were used for the catch-age analysis. The range of ages used for the catch-age analysis was 4 to 12+ with the last age group representing fish aged 12 years or older. Three-year-olds are not fully recruited and fish 12 and older were grouped together because of differences in the ageing technique. Otolith surface readings (1945-72) under-estimate the ages of older fish (beginning at about age 12) compared to readings determined from otolith burnt cross-sections (1973-98).

The catch-age model of Schnute and Richards (1995) was used for this assessment. This model is similar to most other catch-age models (Fournier and Archibald 1982, Methot 1989) but does differ in the specification of the model error structure. Parameters in the model likelihood include standard deviations $\sigma 1$, $\tau 1$, and $\tau 2$, corresponding to the error in the recruitment, biomass index and proportions at age, respectively. The variance ratio $\rho=\sigma_1^2/(\tau_1^2+\tau_2^2)$ must be specified in the likelihood calculation, analogous to emphasis factors in the stock synthesis model of Methot (1989, 1990).

The model sensitivity to changing values for ρ was examined in the previous assessment (Fargo and Kronlund 1997). Briefly, increasing or decreasing ρ explicitly increases or decreases the standard deviation for the recruitment index. Broader confidence intervals for the model estimates of recruitment occurred with high values for ρ and narrower intervals occurred for low values of ρ. Changing the value of ρ ($7 \geq \rho \leq 9$) had virtually no effect on the biomass index and there were no changes in the overall trends for the population estimates. Fargo

(1995) examined the sensitivity of the model to changing values for M. He found that the best fit occurred with M fixed at 0.20 to 0.25. The lower value for M was chosen to provide more conservative estimates of biomass. The natural mortality rate was not treated as a parameter to be estimated by the model. It was fixed at 0.20 and remained constant over time for this analysis. Work by Richards et al. (1997) indicated broader confidence intervals for population estimates when M was treated as a parameter to be estimated. The best fit of the model, as indicated by the model likelihood statistic, occurred with ρ=0.7 and M fixed at 0.20. This is the same configuration that was used in the last assessment (Fargo and Kronlund 1997, Fargo 1998). Details of the model are provided in Appendix A.1.

Input data included landed catch, proportions at age in the catch (numbers), mean weight at age, maturity at age and CPUE estimates for Rock sole (adults) obtained from the Hecate Strait surveys conducted between 1984 and 1998. Mean weight at age was computed for each age group in each year from age-length data using an allometric length-weight relationship derived for this stock. Since 1984 a synoptic survey has been conducted every two years in this area. The survey CPUE data for Rock sole was used to tune the catch-age model.

Biomass and recruitment trajectories from the model are presented in Figure 1.1. Between 1980 and 1995, exploitable biomass for this stock increased to the highest level recorded in the last 50 years. Biomass in 1998 is higher than the long-term average for the 1945 to 98 period. The estimate of exploitable biomass in 1998, B_{98}, was 4854 t $\pm$1303t (for the 95% confidence interval). Between the late 1980s and early 1990s recruitment increased to the highest level on record. Between 1993 and 1995 recruitment declined significantly but has remained relatively stable for the last three years. The uncertainty in both population estimates is highest for the later years, a function of the low number of observations used to determine them. A retrospective analysis performed last year indicated that the terminal estimate of biomass varied by $\pm$ 30% over a span of four years. After five years it had stabilized (Fargo 1998).

The model estimate of fishing mortality for the stock in 1998 was 0.13, about the same level as estimated in last year's assessment (Fargo 1998). Although the current rate of fishing appears to be relatively low, observations from several more years are needed before the terminal population estimates and fishing rate for the stock can be considered accurate.

1.5.1.4 Fishing rate reference points

A class of F reference points associated with recruitment overfishing was determined from survival ratios using the population estimates from catch-age analysis (Shepherd, 1982, Gabriel et al. 1989). The strategy here is to avoid stock collapse by managing fishing effort to maintain a stable spawning biomass expressed as spawning stock biomass per recruit (SSB/R) (Patterson 1992). The SSB/R index was used to evaluate the spawning potential of Hecate Strait Rock sole over a range of fishing mortality rates. The SSB/R calculations are analogous to those in yield per recruit analysis (Gabriel et al. 1989) and when combined with population estimates from catch-age analysis provide a biological reference for maintenance or rebuilding of spawning stock biomass. Rock sole SSB/R ratios were computed over a range of fishing rates (Gabriel et al. 1989) as per yield per recruit calculations. Then, SSB/R was

computed for each year using the population estimates of the catch-age analysis (historical series). The percentiles of the SSB/R historical series were used to identify fishing mortality reference points on the SSB/R / fishing mortality curve (Figure 1.2). Such targets are the F_{low}, F_{med} and F_{high} reference points. These are the fishing mortalities at which the historical data on recruitment suggest that the stock has an over 90% a 50% or a worse than 10% chance of maintaining its spawning stock biomass (Patterson 1992).

The following fishing mortality reference points were estimated in last year's assessment of Hecate Strait Rock sole: $F_{0.1}$=0.22, F_{med}=0.37, F_{max}=0.57 F_{high} =0.63 and F_{low}=0.16 (Fargo 1998). Fishing at a rate equivalent to F_{max} while permitting the maximum yield to be obtained from a stock, has resulted in stock depletion in the past (FAO 1995) and is clearly not relevant for management purposes other than in the short-term. Similarly F_{high} corresponds to a fishing rate that will significantly lower the spawning stock biomass and eventually lead to recruitment overfishing. The target rate F_{med} was intended to serve as an indicator for recruitment overfishing (Sissenwine and Shepherd 1987). That is with the fishing rate below this level the stock will maintain or increase its spawning stock biomass. With the fishing rate above this level the spawning stock biomass will decrease, increasing the probability of poor recruitment which will lead to recruitment overfishing in the long-term. The target fishing mortality reference point $F_{0.1}$ has been advocated by many as a reference point, below F_{med}, to prevent recruitment overfishing (FAO 1995). F_{low} corresponds to a target fishing mortality rate that is consistent with a precautionary management strategy. That is, with the fishing rate at or below this level the spawning stock biomass should increase so that stock rebuilding can take place.

1.5.1.5 Stock status

The results of the catch-age analysis indicate a significant increase in stock biomass occurred between the late 1980s and early 1990s due to strong year-classes produced in the mid 1980s. By the mid 1990s, however, significant declines in recruitment and biomass had occurred. Rock sole CPUE from research trawl surveys conducted in Hecate Strait has declined since the early 1990s as well (Fargo 1998). The El Nino event along the B.C. coast in 1996 and 1997 should produce unfavourable temperature conditions for Rock sole egg development and larvae survival (Forrester and Thomson 1969, Fargo and McKinnell 1989). Thus, recruitment and yield for this stock may continue to decline over the next several years.

1.5.1.6 Recommendations and Yield Options

The fishing mortality reference point $F_{0.1}$, (F= 0.22), was used to estimate sustainable yield for the stock. The $F_{0.1}$ yield was calculated for the 25^{th}, 50^{th} and 75^{th} percentiles of the 95% confidence region for B_{98} (± 1329 t); 3957 t, 4854 t and 5750 t, respectively. The $F_{0.1}$ yield corresponding to these estimates is 779 t, 956 t and 1133 t, respectively. The yield recommendations are unchanged from last year.

Low risk yield option -- A yield of 800 t, is the low-risk sustainable option for these stocks.

High risk yield option -- A yield of 1000 t, is the high-risk sustainable option for these stocks.

1.5.2. English sole - Hecate Strait

1.5.2.1. Introduction

Stock delineation studies conducted by Ketchen (1956) and Fargo et al. (1984) indicate that a single stock of English sole is resident in Hecate Strait. The stock was near the pristine level in the 1940s, declined after large removals in the early 1950s and has remained fairly stable since the late 1960s (Fargo 1998). Both density dependent and density independent factors exert an influence on the abundance of this stock (Fargo 1994). A high rate of Ekman transport through the Strait during the spawning period results in the loss of eggs and larvae due to advection and is associated with subsequent low recruitment. Low recruitment also results when the stock spawning biomass is lower than 30% of the pristine level (Fargo 1994). The stock has produced strong year-classes about once a decade with the latest increase in recruitment occurring in the early 1990s. The age of recruitment is 4 years for females although they are not fully recruited until age 5. Only a small proportion of males attain commercial size. Length at 50% maturity, L_{50}, is 25.5 cm (3 y) for males and 35.1 cm (4 y) for females (Foucher et al. 1989). The contribution of strong year-classes to the fishery usually lasts about 4 or 5 years. The series of annual landing statistics has been updated using data from the 1998 fishery. The age composition data series has been updated with data from samples collected from the 1998 fishery as well. Analysis of the age composition data is the basis for this assessment.

1.5.2.2. Landing statistics

Managers used area-specific quotas as a catch limitation tool in the past. These have undoubtedly had an influence on the fishing patterns of the fleet. In 1996 individual vessel quotas were invoked and at-sea observers were required for all option A vessels. This has resulted in the collection of more comprehensive data but prevents direct comparison with landing statistics for previous years. Annual landing statistics are presented in Table 1.4. Statistics for 1954-98 are calculated directly from data obtained from vessel skipper logs and observer logs. No detailed records are available prior to 1954 and the indices of Ketchen (1980) has been used. English sole landings decreased to 492 t in 1998 from 554 t in 1997 while effort decreased substantially to 725 h from 1286 h over the same period. CPUE in 1998 increased to 0.261 t/h from 0.227 t/h in 1997.

1.5.2.3.1 Catch-age analysis

The catch-age model of Schnute and Richards (1995) was used for this assessment. See section 1.5.1.3 for information about the model configuration and Appendix A.1. for details of the model. The age composition data series for this stock was updated with age determinations for samples collected during the 1998 trawl fishery. The range of ages used for catch-age analysis was 4 to 12+ with the last age group representing fish aged 12 years or

older. Fish are fully recruited by age 4 while fish of 12 years and older were grouped together because of differences in the ageing technique used over time. Otolith surface readings (1945-72) under-estimate the ages of older fish (beginning at about age 12) compared to readings made from otolith burnt cross-sections (1973-98). The full compliment of years where data was available, 1944-98, was analysed. Input data for the model included landed catch, proportions at age in the catch weight at age and annual CPUE estimates for English sole from the Hecate Strait research trawl surveys conducted every two years between 1984 and 1998. The CPUE index was used to tune the catch-age model.

Biomass and recruitment trajectories from the model are presented in Figure 1.3. Between 1950 and the mid 1960s the biomass of this stock declined significantly. Between the mid 1960s and the mid 1970s it rebuilt and it has fluctuated without trend since that time. The estimate of exploitable biomass in 1997, B_{98}, was 3005 t ± 366 t, (for the 95% confidence interval). Biomass in 1998 was near the long-term average for the last 50 years. A retrospective analysis performed last year indicated that the terminal estimate of biomass varied by ± 20% over a span of four years but after five years it had stabilized (Fargo 1998). Recruitment increased to the highest level on record in the early 1990s and has declined steadily since that time although the values for 1997 and 1998 are very similar. As in the case of rock sole the uncertainty in the population estimates is greatest for the later years. The model estimate of fishing mortality for the stock in 1998 was 0.16, the same as that in 1997.

1.5.2.4. Fishing rate reference points

Spawning stock biomass per recruit analysis was applied to the data for Hecate Strait English sole. The spawning stock biomass per recruit ratios for English sole were computed over a range of fishing rates (Gabriel et al. 1989) to produce the yield curve in Figure 1.4. The percent quantiles of the historical series of spawning stock biomass per recruit were used to identify fishing mortality reference points on the curve. Such targets are the F_{low}, F_{med} and F_{high} reference points. These are the fishing mortalities at which the historical data on recruitment suggest that the stock has an over 90% a 50% or a worse than 10% chance of maintaining its spawning stock biomass (Patterson 1992).

The target fishing mortality references points estimated for this stock in last year's assessment were: $F_{0.1}$=0.25, F_{med}=0.28, F_{low}= 0.11, F_{high} =0.50 and F_{max}=0.83 (Fargo 1998). These represent exploitation rates than can be used by managers as fixed strategies for achieving sustainable yield or stock rebuilding. Fishing at a rate equivalent to F_{max} while permitting the maximum yield to be obtained from a stock, has resulted in stock depletion in the past (FAO 1995) and is clearly not relevant for management purposes other than in the short-term. Similarly F_{high} corresponds to a fishing rate that will significantly lower the spawning stock biomass and eventually lead to recruitment overfishing. The target rate F_{med} was intended to serve as an indicator for recruitment overfishing (Sissenwine and Shepherd 1987). That is with the fishing rate below this level the stock will maintain or increase its spawning stock biomass. With the fishing rate above this level the spawning stock biomass will decrease, increasing the probability of poor recruitment which will lead to recruitment overfishing in the long-term. The target fishing mortality reference point $F_{0.1}$ has been advocated by many as a reference point,

below F_{med}, to prevent recruitment overfishing (FAO 1995). F_{low} corresponds to a target fishing mortality rate that is consistent with a precautionary management strategy. That is, with the fishing rate at or below this level the spawning stock biomass should increase so that stock rebuilding can take place.

1.5.2.5 Stock status

The distribution of 1998 biomass estimate, B_{98} , 3005 t was used to estimate yield using the reference point of $F_{0.1}$ (F=0.25). The $F_{0.1}$ yield was calculated for the 25th, 50th and 75th percentiles of the 95% confidence region for B_{98} (± 366 t); 2753 t, 3005 t and 3257 t, respectively. The corresponding yields were 608 t, 664 t, and 720 t respectively. There is no change in yield recommendations from last year.

1.5.2.6. Recommendations and Yield Options

Low risk yield option -- A yield of 500t t, is the low-risk option.

High risk yield option -- A yield of 600 t, is the high-risk option.

1.5.3 Dover sole (Areas 5C-E)

1.5.3.1 Introduction

The fishery for Dover sole in Areas 5C-E takes place in northern Hecate Strait at 100 to 160 m depths between May and October, and off the west coast of the Queen Charlotte Islands at 400 to 800 m depths from December to April. The seasonal shift in the fishery is related to the bathymetric spawning migration for the species. The fishery off the west coast of the Queen Charlotte Islands takes place on a spawning population. Dover sole begin to recruit to the fishery at 5 years of age but are not fully recruited until age 7-8. The Dover sole fishery in area 5C-E was unregulated prior to 1981 when annual quotas were first applied.

1.5.3.2 Area 5CDE Landing Statistics

As in other cases the CPUE index for this fishery deteriorated in the 1980s due to the combined effect of changes in management and vessel efficiency. Also, after 1996 annual statistics are not directly comparable to those in previous years because of the implementation of the at-sea observer program and individual vessel quotas (IVQs). Landing statistics for Dover sole from the Area 5C-E trawl fishery for 1970-98 are presented in Table 1.5. Landings increased to 1043 t in 1998 from 714 t in 1997 while effort decreased to 1520 h in 1998 from 1563 h in 1997 and CPUE increased to 0.422 t/h in 1998 from 0.326 t/h in 1998.

1.5.3.4. Stock status

Estimates of the total mortality rate, Z, estimated from age composition data in 1996-97 ranged between 0.15 to 0.27 (Fargo 1998). No age composition data were available for the 1998 fishery. Estimates of the rate of fishing mortality for the stock in 1996 and 1997 ranged from 0.10 to 0.15 while $F_{0.1}$ for the stock is 0.13 (Fargo 1998). The level of effort in 1998 was similar to that in 1997. Thus, the yield recommendations for the 2000 fishery remain the same as those for the 1999 fishery.

1.5.3.4 Recommendations and Yield Options

Low risk yield option:

A yield of 800 t, equivalent to the MSY estimated using surplus production analysis (Fargo 1998).

High risk yield option:

A yield of 1200 t is suggested as an upper limit for yield for the area 5CDE Dover sole stock using results from a length-based analysis (Fargo 1991).

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Table 1.1. Yield options for British Columbia flatfish species/stocks 1999-00

		1999		2000	
Species	Area	low risk	high risk	low risk	high risk
Dover sole	Area 3C-D	1000 t	1500 t	1000 t	1500 t
	Area 5C-E	800 t	1200 t	800 t	1200 t
Rock sole	Area 5C-D	800 t	900 t	800 t	900 t
English sole	Area 5C-D	500 t	600 t	500 t	600 t

Table 1.2 Annual landing statistics for the Area 3CD Dover sole trawl fishery, 1980-98.

Year	Landings (t)	Effort[a] (h)	CPUE[b] (t/h)
1980	184	306	0.556
1981	171	461	0.339
1982	129	281	0.361
1983	22	84	0.389
1984	24	79	0.256
1985	3	9	0.280
1986	2	8	0.321
1987	1	4	0.143
1988	371	620	0.426
1989	1115	1754	0.415
1990	1122	1882	0.402
1991	1222	2572	0.316
1992	1382	3034	0.357
1993	1785	4459	0.318
1994	1492	4626	0.267
1995	1630	5352	0.259
1996	1083	2318	0.229
1997	788	1876	0.263
1998	1092	1829	0.349

[a] Annual effort for 25% qualified landings
[b] Median CPUE for 25% qualified landings

Table 1.3. Canada-U.S. landing statistics for Hecate Strait Rock sole, 1945-98.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]	
	45	121	434	0.279
	46	410	2228	0.184
	47	1181	1946	0.607
	48	901	1753	0.514
	49	657	1352	0.486
	50	784	1452	0.540
	51	1024	944	1.085
	52	2292	2014	1.138
	53	779	1227	0.635
	54	926	840	0.938
	55	1560	1558	0.680
	56	1160	1484	0.644
	57	1151	2019	0.443
	58	1256	1331	0.650
	59	416	636	0.403
	60	1127	1100	0.680
	61	744	694	0.900
	62	829	849	0.735
	63	881	735	0.737
	64	743	835	0.531
	65	879	629	0.545
	66	2544	2491	0.598
	67	2162	2324	0.511
	68	2366	4209	0.386
	69	1461	4485	0.314
	70	1403	3660	0.326
	71	1503	3587	0.255
	72	515	650	0.337
	73	507	619	0.435
	74	622	603	0.475
	75	1204	1912	0.360
	76	1438	1830	0.402
	77	846	1896	0.285
	78	874	1662	0.336
	79	1313	1943	0.330
	80	977	2420	0.254
	81	584	806	0.287
	82	291	841	0.209
	83	247	499	0.286
	84	188	573	0.188
	85	112	276	0.242
	86	219	470	0.345
	87	536	577	0.389
	88	1402	2520	0.410
	89	1422	3757	0.288
	90	1519	3948	0.319
	91	2666	6552	0.295
	92	2226	5777	0.289
	93	2080	5851	0.301
	94	1384	4282	0.275
	95	1294	3538	0.322
	96	670	2336	0.207
	97	677	2667	0.191
	98	576	2395	0.182

[a] Annual effort for 25% qualified landings.
[b] Median CPUE for 25% qualified landings

Table 1.4. Canada-U.S. landing statistics for Hecate Strait English sole, 1944-98.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]
44	152	215	0.707
45	304	365	0.832
46	470	809	0.581
47	350	538	0.651
48	937	2740	0.342
49	795	1893	0.420
50	2622	4910	0.534
51	1024	2142	0.478
52	1347	3293	0.409
53	871	2084	0.418
54	455	563	0.362
55	875	744	0.401
56	956	1344	0.349
57	552	640	0.244
58	693	617	0.337
59	940	772	0.315
60	1147	1058	0.333
61	871	1615	0.298
62	459	903	0.247
63	408	568	0.207
64	436	441	0.272
65	414	326	0.317
66	362	354	0.302
67	534	535	0.411
68	671	844	0.302
69	819	1314	0.390
70	1002	2042	0.312
71	488	1585	0.192
72	371	550	0.230
73	667	514	0.411
74	500	519	0.519
75	938	1015	0.466
76	1133	1627	0.275
77	1179	2201	0.310
78	559	944	0.246
79	864	980	0.337
80	995	1105	0.327
81	1327	2149	0.249
82	428	1062	0.219
83	430	834	0.240
84	658	1129	0.290
85	585	1520	0.226
86	335	469	0.365
87	630	396	0.347
88	688	540	0.493
89	826	925	0.385
90	992	1335	0.383
91	913	940	0.308
92	987	1602	0.307
93	1421	2636	0.295
94	1000	1860	0.343
95	1190	2321	0.320
96	455	570	0.310
97	554	1286	0.227
98	492	725	0.261

[a] Annual effort for 25% qualified landings.
[c] Median CPUE for 25% qualified landings

Table 1.5. Canada-U.S. landing statistics for Dover sole, Areas 5C-E, 1970-98.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]
70	965	1324	0.590
71	903	1367	0.556
72	922	1495	0.543
73	768	910	0.679
74	767	878	0.687
75	882	1135	0.573
76	1022	1465	0.440
77	577	900	0.319
78	483	650	0.497
79	697	1057	0.333
80	807	724	0.416
81	840	1079	0.428
82	512	894	0.433
83	693	544	0.568
84	953	1526	0.448
85	830	1039	0.485
86	1040	931	0.562
87	503	432	0.549
88	649	652	0.594
89	696	775	0.567
90	787	1181	0.542
91	649	1041	0.428
92	883	1444	0.381
93	1508	2767	0.414
94	1418	3117	0.371
95	1587	4220	0.320
96	1133	2245	0.308
97	714	1563	0.326
98	1043	1520	0.422

[a] Annual effort for 25% qualified landings.
[b] Median CPUE for 25% qualified landings

Appendix. A.1 Schnute and Richards (1995) Catch-age model

The catch-age model used for the assessments of Hecate Strait rock and English soles is an application of the state space model developed by Schnute and Richards (1995). The model attempts to reconstruct the population history from known controls and observations. In this context, the catch biomass acts as a known control on the population dynamics. Observations, including proportions at age in the catch and a biomass index from survey CPUE values, describe the current state of the system. The model relates the observations, measured with error, to unknown numbers of fish in the population.

Table A.1 contains a deterministic version of the model, with notation described in Table A.2. Equations in Table A.1 are tailored for each application. In particular, the Schnute-Richards model is based on numbers of fish; we use known weights, w_{at} of fish of age a at time t and the maturity ogive m_a to determine the spawning biomass S_t and exploitable population biomass B_t.

Similar to other stochastic catch-age models, our analysis contains a separability assumption. The two parameters α and β_1 describe a selectivity function which is time-independent and asymptotic with age. The quantity β_a in equation (A.2) denotes the proportion of age a fish that are vulnerable to the fishery.

Other quantities in the parameter vector Θ are the natural mortality rate M, the survey catchability q, and the time series of recruitments R_t. We treat the recruitments as parameters to be estimated from the data; our analysis does not contain an explicit stock-recruitment function.

The prediction equations (A.14) and (A.15) relate quantities $\bar{I}_t$ and $\bar{p}_{at}$ obtained from the model dynamics to observations I_t and p_{at} of survey CPUE and age proportions, respectively. (We use the convention of a bar over a quantity to denote a prediction for that quantity.) We assume in (A.14) that the survey CPUE indexes the population biomass after half of the annual catch has been removed. The catchability q converts units of population biomass into units of CPUE. Although the relationship (A.14) could be made age-specific, age composition data are not available for the early surveys. The predicted age proportions in the catch are obtained from the underlying population age structure in equation (A.4).

Schnute and Richards (1995) specify stochastic counterparts of the deterministic equations (Table A.1), model residuals, and the model likelihood function. They impose three sources of error: (1) autoregressive lognormal process error among the recruitments R_t;(2) lognormal error in CPUE; and (3) multivariate logistic error in the observed proportions p_{at}. These error structures lead to residual functions

$$\xi_t = \log I_t - \log \bar{I}_t$$

$$\eta_{at} = \log p_{at} - \log \bar{p}_{at} - \frac{1}{A}\sum_{a=1}^{A}[\log p_{at} - \log \bar{p}_{at}]$$

that describe model relationships between predictions and observations of survey CPUE and age proportions, respectively.

The likelihood for this catch-age model conforms to the errors-in-variables paradigm (Schnute 1994); apparent variations in abundance can be explained through high process error σ in recruitment or high measurement error τ in CPUE. Schnute and Richards (1995) resolve this ambiguity by fixing the model variance ratio, $\rho = \frac{\sigma^2}{\sigma^2 + \tau^2}$, between the recruitment variance and the total variance($\sigma^2 + \tau^2$).

For the catch-age analysis, we fix the variance ratio ρ=0.7, a value that represents moderate levels of error in both recruitment and survey CPUE. Similar stock reconstructions were obtained for a range of reasonable choices of ρ in preliminary model runs. We also employ a fixed natural mortality rate of M=0.2. Age classes in the model range from recruits to the fishery at age 4 to an accumulator age class for age 12 and older. To reduce the influence on the model likelihood of very small age proportion observations (obtained from a small number of fish), we group consecutive age classes such that $p_{at} \geq 0.02$ for each age a and time t (Richards et al. 1997).

The model was implemented using AD Model Builder software (Otter Research Ltd. 1994). Standard errors for the model parameters and other quantities were obtained from the model hessian matrix. These allow calculation of symmetric confidence intervals, assuming that the parameter estimates have a multivariate normal distribution. In particular, we used AD Model Builder to compute standard errors for log recruitment, log spawner biomass and log exploitable biomass.

Table A.1. Deterministic catch-age model. Calculations begin with the parameter vector Θ and proceed recursively to define all states and observations.

Parameters

(A.1) $\Theta = (\alpha, \beta_1, M, q, \{R_t\}_{t=2-A}^{T})$

Selectivity

(A.2) $\beta_a = 1-(1-\beta_1)\left(\frac{A-a}{A-1}\right)^{\alpha}$

State moments

(A.3) $P_t = \sum_{a=1}^{A} \beta_a N_{at}$

(A.4) $u_{at} = \beta_a N_{at} / P_t$

(A.5) $B_t = \sum_{a=1}^{A} \beta_a w_{at} N_{at}$

(A.6) $S_t = \sum_{a=1}^{A} m_a w_{at} N_{at}$

(A.7) $C_t = D_t / \sum_{a=1}^{A} u_{at} w_{at}$

(A.8) $F_t = \log\left(\frac{P_t}{P_t - C_t}\right)$

Initial states

(A.9) $N_{a1} = R_{2-a} e^{-M(a-1)}$; $1 \leq a < A$

(A.10) $N_{A1} = R_{2-A}\left(\frac{e^{-M(A-1)}}{1-e^{-M}}\right)$

State Dynamics

(A.11) $N_{1t} = R_t$

(A.12) $N_{at} = e^{-M}[N_{a-1,t-1} - u_{a-1,t-1} C_{t-1}]$; $2 \leq a < A$

(A.13) $N_{At} = e^{-M}[N_{A-1,t-1} + N_{A,t-1} - (u_{A-1,t-1} + u_{A,t-1}) C_{t-1}]$

Predicted Observations

(A.14) $\bar{I}_t = q(B_t - 0.5 D_t)$

(A.15) $\bar{p}_{at} = u_{at}$; $2 \leq a \leq A$

Appendix table 1.1. Description of the notation for the input data, parameters, and other calculated model quantities in Table A.1.

Symbol	Description
	Index quantities
a	age-class from 1 to A
t	year from 1 to T
	Input data
D_t	observed catch biomass in year t
I_t	observed survey CPUE in year t
m_a	proportion of age-class a fish which are mature
p_{at}	observed proportion of age-class a fish in the year t catch
w_{at}	weight of age-class a fish in year t
	Parameters
Θ	parameter vector
α	selectivity slope parameter
β_1	selectivity of age-class 1
M	natural mortality rate
q	catchability for survey CPUE
R_t	age-class 1 recruitment in year t
	Calculated quantities
β_a	selectivity for age-class a
B_t	exploitable population biomass at the start of year t
C_t	catch number in year t
F_t	fishing mortality rate in year t
N_{at}	number of age-class a fish at the start of year t
P_t	exploitable population numbers at the start of year t
S_t	spawning stock biomass at the start of year t
u_{at}	exploitable proportion of age-class a fish in year t catch

Appendix table 1.2 Values for biological statistics used in the yield per recruit and spawning stock biomass per recruit analysis.

Parameter or calculated value	Rock sole	English sole
K	0.211	0.275
$L\infty$	50.5 cm	49.4 cm
$W\infty$	1847 g	1091 g
t_0	-0.120	-0.039
M	0.20	0.20
t_r	4	4
w_j	503 629 745 869 985 1111 1180 1268 1315	369 424 478 535 595 662 723 772 848
l_j	33.6 36.0 37.9 39.7 41.3 42.9 43.7 44.7 45.2	34.6 36.2 37.6 39.0 40.3 41.6 42.8 43.7 45.1
p_j	0.034 0.474 0.910 0.991 0.998 1.000 1.000 1.000 1.000	0.470 0.894 0.978 0.993 1.000 1.000 1.000 1.000 1.000

Where:

K, $L\infty$, $W\infty$ and t_o are von Bertalanffy growth curve coefficients

M is the instantaneous rate of natural mortality

w is the mean weight at age in grams

l is the mean length at age in centimetres

p is the proportion mature at age

and : $_j$ indexes age groups 4-12+

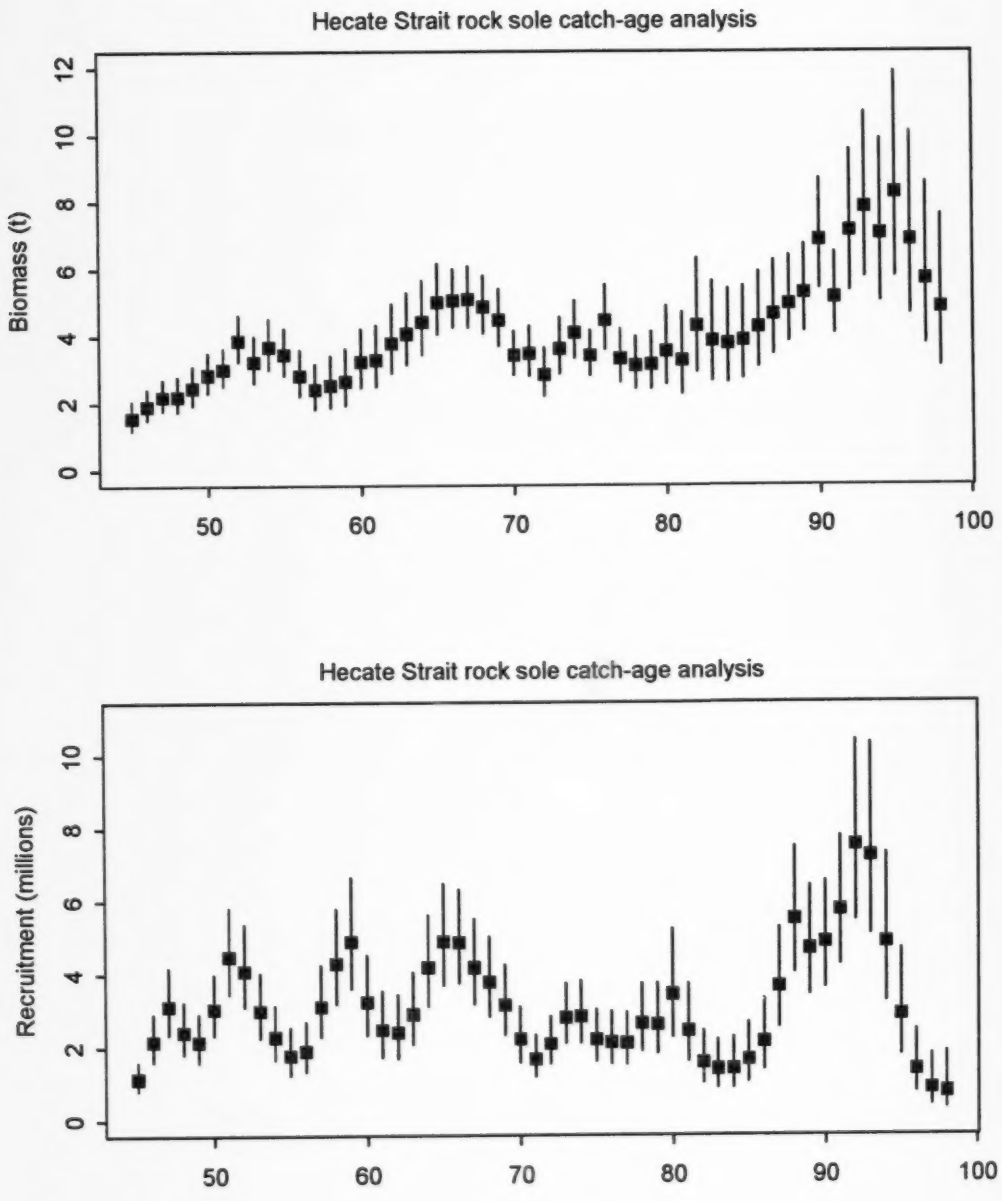

Figure 1.1. Biomass and recruitment trajectories (1945 -98) from the catch-age analysis for Hecate Strait Rock sole. The vertical bars represent the 95% confidence limits for individual estimates.

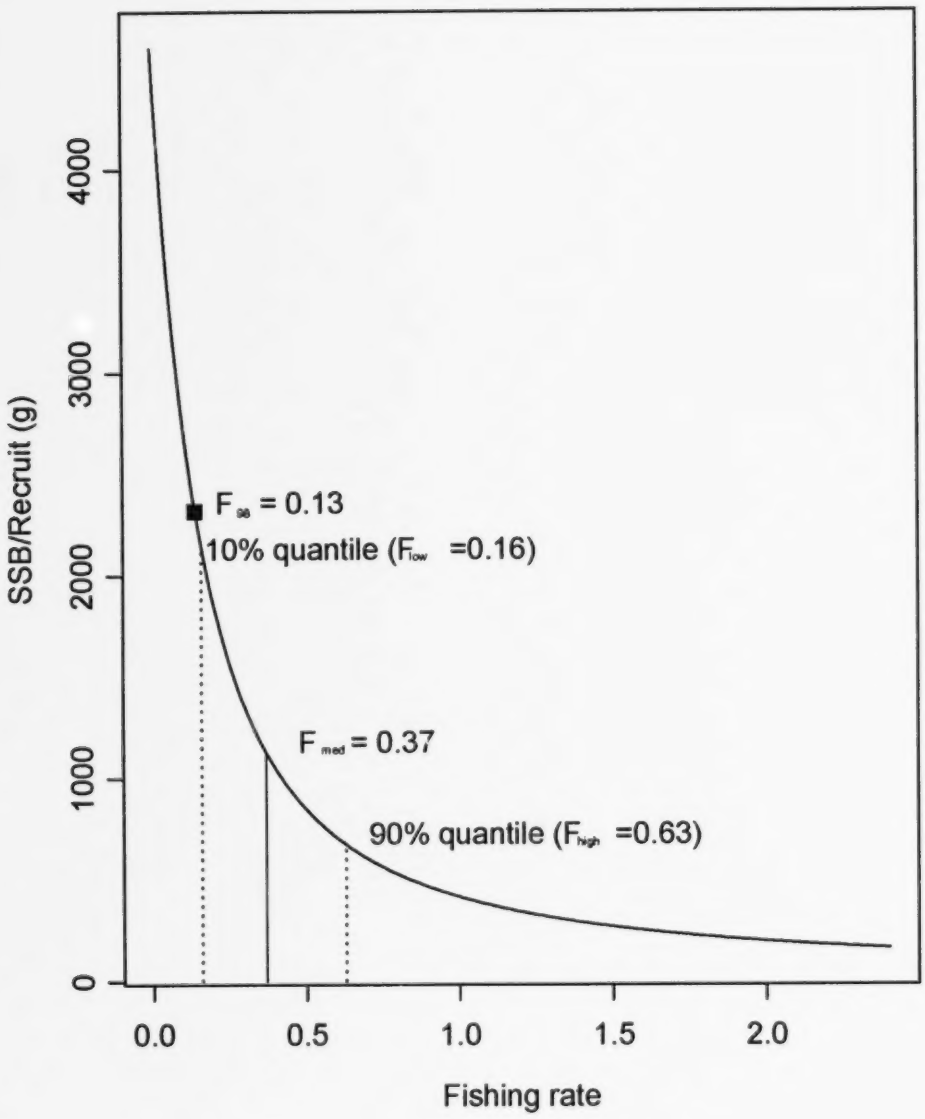

Figure 1.2. Results from the spawning stock biomass per recruit analysis for Hecate Strait Rock sole. The solid line indicates the fishing mortality rate where the stock has a 50% chance of maintaining its spawning biomass (F_{med}). The dotted lines indicate the fishing rates associated with the 10^{th} and 90^{th} quantiles (F_{low} and F_{high}, respectively) of the SSB/R index computed from the rock sole catch-age analysis.

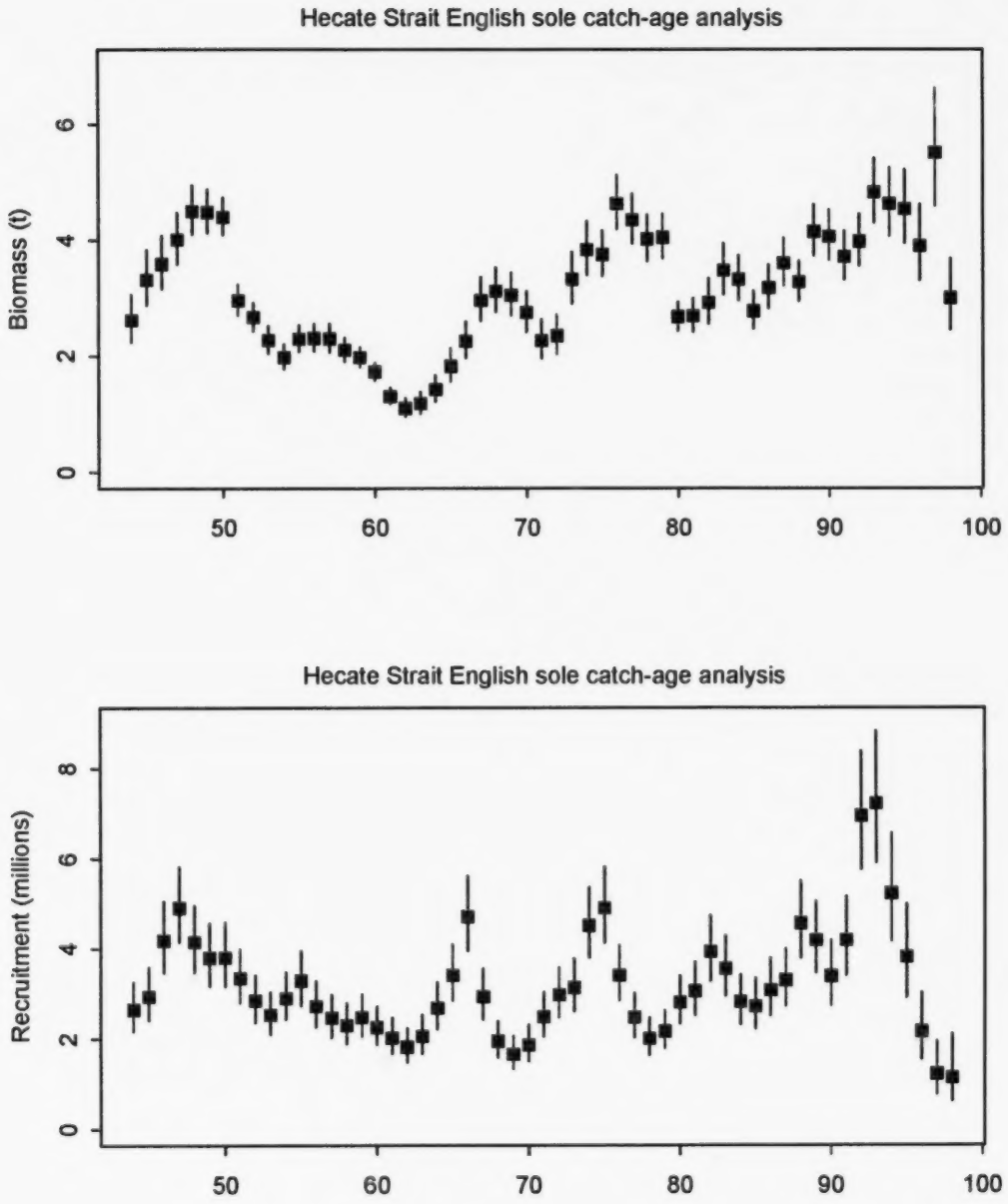

Figure 1.3. Biomass and recruitment trajectories (1945-98) from the catch-age analysis for Hecate Strait English sole. The vertical bars represent the 95% confidence limits for individual estimates.

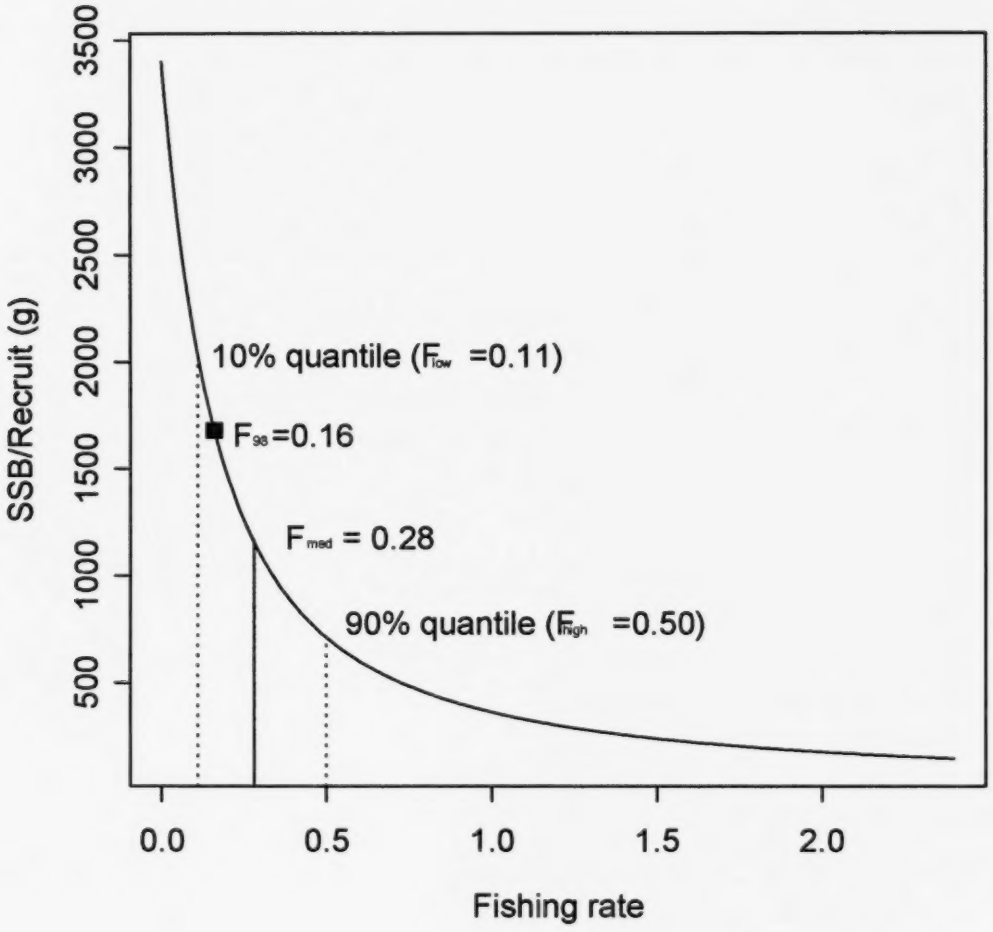

Figure 1.4. Results from the spawning stock biomass per recruit analysis for Hecate Strait English sole. The solid line indicates the fishing mortality rate where the stock has a 50% chance of maintaining its spawning biomass (F_{med}). The dotted lines indicate the fishing rates associated with the 10% and 90% quantiles (F_{low} and F_{high}, respectively) of the SSB/R index computed from the population estimates from catch-age analysis.